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Abstract

The context of this paper is the measurement of welfare and weak sustainability, defined as non-declining utility, in dynamic economies, i.e., green, environmental or comprehensive accounting. We estimate the green net national product and genuine saving for Portugal 1991-2005, accounting for the disamenity of air pollution emissions, the depreciation of commercial forests - pine and eucalyptus -, the value of time (through technological progress), excluding the effect of business cycles and discussing the assumptions behind the usual terms included in the empirics of comprehensive accounting. For the accounting period considered we find that both GNNP and GS are positive, thereby indicating no sustainability problem in Portugal, although both GNNP and GS depict a trend towards unsustainability. Excluding technological progress there is a contradiction in the sustainability message: GS is negative after 2002, whereas GNNP is always positive, indicating that welfare increased.

Keywords: Welfare measures; green accounting; technological progress, business cycles

JEL Classification: Q20, C51, C55

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1. Introduction

The study of sustainability with the tools of the theory of dynamic economies has provided support for the use of sustainability indicators based on national accounting. This line of research has been termed green, comprehensive or environmental accounting and it evolved since the 70's both in theoretical and empirical applications, through the efforts of individual countries or practitioners, each developing their own frameworks and methodologies to represent their environmental priorities. Since the early 90s, concerted efforts have been underway through the United Nations Statistics Division, the European Union, the OECD, the World Bank, country statistical offices and other organizations, to standardize methodologies. These efforts resulted in the publication of the UN's handbook on environmental accounting in 1993 and its revision in 2003 (UN, 2003). Environmental accounts have four components: natural resource asset accounts; pollutant, energy and resource flow accounts; environmental protection and resource management expenditures; and environmentally-adjusted macroeconomic aggregates. Here we estimate two environmentally-adjusted aggregates for Portugal – green net national product (GNNP, also known as green GDP) and genuine (or adjusted net) savings (GS).

Regarding the theoretical background for this approach, Weitzman (1976), in a constant population, discounted utilitarian context with linear utility and no technological progress, was able to show that the current net national product, NNP, measured as the sum of consumption and net investment, is proportional to the current maximum welfare attainable along the optimal path. This result suggests that welfare is improving if NNP is improving. It should be stressed that the concepts of consumption and net investment are interpreted to include all that influences current welfare. This includes, in addition to physical capital, natural resources, environmental (dis)amenities and stocks of knowledge. Comprehensive net investment has been termed genuine saving by Hamilton and Clemens (1999), or, more recently in the World Bank estimates, adjusted net savings, and has the interpretation that an economy having consistently negative genuine savings will experience decreasing welfare in the future, i.e., its development is unsustainable. This savings measure of unsustainability is rooted in the Hartwick rule, which is associated with the prescription of holding the value of net investments constant and equal to zero to obtain constant utility (Asheim et al., 2003).

Asheim and Weitzman (2001) provided an important contribution towards empirical estimation of GNNP and GS in generalizing the Weitzman's (1976) results by proving that the welfare and sustainability interpretation of GNNP and GS holds even when utility is not a linear function of a bundle of consumption goods, if GNNP is deflated by a Divisia consumer price index (CPI). The interpretations still hold even if welfare is not given by a discounted utilitarian welfare function (Asheim, 2007). Other ways to deflate GNNP to obtain a comprehensive measure of welfare have been suggested, for instance using the conventional NNP deflator (Li and Löfgren, 2006). Although the debate on how to deflate GNNP is still unresolved (see Sefton and Weale, 2006; Li and Löfgren, 2006; and Asheim, 2007), we follow the CPI approach here.

A (un)sustainability test was obtained by Pezzey (2004) that shows that an economy with population growth and exogenous time changes is unsustainable, at some time, if either net investment or the change in GNNP is zero or negative. In Pezzey (2004) the time in GNNP and GS is treated as a productive stock, which can include the value of future exogenous changes in technology, terms of trade or other externalities. With this interpretation of time in the production function, the technological progress can have positive or negative impacts on welfare.

Regarding the empirical applications of environmental accounting, the literature is dispersed and many studies are not published in scientific journals. It is not our intent here to be thorough but rather to provide a bird's eye view of green accounting empirical applications. Vincent and Hartwick (1998) reviewed more than 30 studies, of which more than 20 since the late 1980s, which estimated either GNNP or GS. More recently, Lange (2003) reports on several industrialized and developing countries with environmental accounting programs of which 6 estimate macro aggregates. Overall, these studies extend the usual accounting system to include non-market goods and services from natural resources like forest and agricultural resources, fisheries, subsoil assets (oil and mineral resources) depletion, and several environmental (dis)amenities. On average, the adjustment for the depletion of natural resources ranges from 0.2 to 4 % of GDP. Most of these studies concerned developing economies and most of the studies of developed countries are concerned with forest resources and environmental amenities, such as biodiversity and landscape value. Usually the environmental accounting studies do not deal with damages from pollution. In this respect, Hamilton and Atkinson (1996) devised a simple model for flow pollutants (local effects) and found that GS ranged from 4 % to 14 % of GDP in Europe and that, total air pollution damage is 1 to 8 % of GDP. The set of pollutants they consider is not the same we consider here, as we explain in section 3.1. For stock pollutants we mention the World Bank's GS estimates that include the global climate damages of CO_2, and the health damages from particles.

The first estimates of GS were reported by Pearce and Atkinson (1993). They used saving data for 18 countries to calculate GS, and their results suggest that many countries are unlikely to pass a sustainability test. Currently, the World Bank provides online estimates of adjusted net savings that are a proxy of the true rate of savings after taking into account investments in human capital, depletion of natural resources and damage caused by air emissions. For the world as whole, net forest depletion is around 0.05%, energy depletion is around 3% of gross national product or income (GNP or GNI), mineral depletion averages 0.2% of GNP, the damage from CO_2 emissions is around 0.4% of GNP and from particles is 0.5%.

Most empirical studies ignore technical progress and shifts in terms of trade. On this topic, we mention Weitzman (1997) on exogenous technical progress, Vincent et al. (1997) on exogenous shifts in oil export prices and Pezzey et al. (2006) on both. Pezzey et al. (2006) found that the part due to future oil prices is much smaller than the contribution from the future growth in production possibilities through technical progress. The empirical results suggest that, by neglecting exogenous technological growth, one obtains a downward biased estimate of GNNP. This bias can be as high as 40-50%, i.e., yearly NNP should be scaled by 1.4-1.5.

The theory supporting environmental accounting also allows for other kinds of extensions to national accounts' aggregates towards a better measure of well-being. In this regard, Boarini et al. (2006) propose alternative measures of well-being, to include aspects that affect the quality of life of households but that are outside national accounting systems, namely, leisure time, the size of the household and income inequality.

Section 2 summarizes the theory and results behind GNNP and GS in a general setting and in the case of a small open economy. Section 3 describes the data for Portugal while commenting on its drawbacks and use. The estimates of GNNP and GS are also presented in section 3, along with its analysis excluding business cycles. Section 4 concludes.

2. The theory of comprehensive accounting

2.1 General model

Here we present a summary of the comprehensive accounting results that can be found in the literature. Consider a representative agent, competitive, open economy with constant population. The consumption bundle $\mathbf{C}(t)$ contains everything that influences well-being $U(\mathbf{C}(t))$,[2] including all non-market commodities (environmental or produced at home) and externalities. The economy's controlled stocks include physical, financial, natural and human capital (education and knowledge accumulated in R&D), forming a vector $\mathbf{K}(t)$, with net (of depreciation) investment, $\dot{\mathbf{K}} = \mathbf{I}$. The production possibilities set constrains the decisions to invest and consume such that $\left(\mathbf{C}(t), \mathbf{I}(t)\right) \in S\left(\mathbf{K}(t), t\right)$, where S represents the attainable production possibilities. The time argument denotes an uncontrolled stock that causes changes in production possibilities frontier such as exogenous technological progress or other externalities.

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[2] The convention throughout the text is that vectors are represented in bold.

The representative agent, seeking to maximize welfare, $\int_0^\infty U(\mathbf{C}(t))e^{-\rho t}dt$, with a constant and positive utility discount rate, ρ, chooses the paths of consumption and net investment subject to the attainable production possibility set, obeying the initial conditions for the stocks of capital. The following results are on the optimal path $\left(\mathbf{C}^*(t), \mathbf{I}^*(t), \mathbf{K}^*(t)\right)$ of the above problem so for ease of exposition we abstain from using asterisks. The maximized dynamic welfare is defined as $W^*(t) := \int_t^\infty U(\mathbf{C}^*(s))e^{-\rho(s-t)}ds$, and using the appropriate Divisia CPI to transform utility metrics into real money prices, real NNP $Y(t)$ is defined as

$$Y = \mathbf{P}\cdot\mathbf{C} + \mathbf{Q}\cdot\mathbf{I} + Q^t, \tag{1}$$

where $\mathbf{P}(t)$ and $\mathbf{Q}(t)$ are the vectors of real prices for consumption and net investment. $\mathbf{P}(t)\cdot\mathbf{C}(t)$ then represents real consumption expenditures and $\mathbf{Q}(t)\cdot\mathbf{I}(t)$ real net investment (genuine saving). The vectors of real Divisia prices for consumption and net investment are defined, respectively, as, $\mathbf{P} := (\partial U/\partial \mathbf{C})/\Lambda$, $\mathbf{Q} := \mathbf{\Psi}/\Lambda$ and $Q^t := \Psi^t/\Lambda$, where $\mathbf{\Psi}(t)$ and $\Psi^t(t)$ are respectively the shadow prices of capital and time, $\mathbf{\Lambda}(t) > 0$ is an extended price index (Pezzey et al., 2006) verifying the Divisia property in continuous time $\dot{\mathbf{P}}\cdot\mathbf{C} = 0$. Using the above definitions, Asheim and Weitzman (2001) show that growth in $Y(t)$ indicates welfare improvement. Formally

$$\dot{Y} = R(\mathbf{Q}\cdot\mathbf{I} + Q^t) = R/\Lambda\dot{W}, \tag{2}$$

where $R := \rho - \dot{\Lambda}/\Lambda$ is the real interest rate. The value of time is $Q^t(t) = \int_t^\infty Y_s(s)e^{-R(s-t)}ds$ (Pezzey, 2004). Thus, if $R(t) > 0$, instantaneous changes in real NNP deflated by a consumer price index have the same sign as changes in welfare. Thus, provided that the real interest rate is positive, growth in real net product (deflated by a consumer price index) in fixed net investment prices can be used to measure welfare improvement along the optimal path (Asheim, 2007). Defining a sustainable development path in terms of non-decreasing utility, Pezzey's (2004) 'one-sided unsustainability test' is:

$$\mathbf{Q}\cdot\mathbf{I}+Q^{t}\leq 0 \text{ or } \dot{Y}\leq 0 \Rightarrow \text{ decreasing utility in the future.} \tag{3}$$

However, positive net investment or genuine saving do not entail that the economy is sustainable (Pezzey, 2004). So far, no general test for sustainability is known.

2.2 Small open economy

In this section we present a particular case of the general model, for a small open economy that follows from Pezzey et al. (2006). We wish to include the stocks of commercial forest, the welfare costs of air emissions and the value of technological progress. The vector of capital assets is now $\mathbf{K}:=(K,K^{f},\mathbf{S})$. $\mathbf{S}(t)$ represents the vector of stocks of commercial forests, $K(t)$ the stock of domestic man-made capital, which grows at the rate of gross investment minus consumption of fixed capital (CFC), as in $\dot{K}=I-CFC$, and $K^{f}(t)$ represents the stock of net foreign capital held privately or by the government, which earns a return at the exogenous, constant world interest rate *r*. Let $K^{f}(t)$ grow as a result of interest on capital plus net exports of the consumption/investment good, $X(t)-M(t)$, and net resource exports, $\mathbf{Q}^{R}\cdot(\mathbf{R}^{X}-\mathbf{R}^{M})$, at world resource prices, $\mathbf{Q}^{R}(t)$, according to

$$\dot{K}^{f}=rK^{f}+X-M+\mathbf{Q}^{R}\cdot(\mathbf{R}^{X}-\mathbf{R}^{M}). \tag{4}$$

The stock of commercial forests is harvested for domestic use in the production process, $\mathbf{R}^{d}(t)$, and to export, $\mathbf{R}^{X}(t)$, and regenerates at the natural rate, $\mathbf{G}(\mathbf{S}(t))$. Therefore, $\mathbf{S}(t)$ changes according to

$$\dot{\mathbf{S}} = \mathbf{G}(\mathbf{S}) - \mathbf{R}^d - \mathbf{R}^X . \tag{5}$$

Production, with exogenous technological progress[3], uses the stock of man-made capital along with the commercial resources harvested for domestic use and imported to produce a consumption/investment good according to $F(K, \mathbf{R}^d + \mathbf{R}^M, t)$. So, the production and net imports of the good, $F(K, \mathbf{R}^d + \mathbf{R}^M, t) + M - X$ are used for consumption $C(t)$, gross investment $\dot{K}(t) + CFC(t)$, firms' total pollution abatement expenditure is $a(t) = \sum_j a^j$ for each pollutant *j*, and harvesting, with the firms' harvesting costs, $f(\mathbf{R}^d + \mathbf{R}^X, \mathbf{S})$. Formally,

$$\dot{K} = F(K, \mathbf{R}^d + \mathbf{R}^M, t) + M - X - C - a - f(\mathbf{R}^d + \mathbf{R}^X, \mathbf{S}) - CFC . \tag{6}$$

The household's utility function is $U(\mathbf{C}) := U(C, \mathbf{E})$, where $C(t)$ is material consumption and $\mathbf{E}(t)$ is the vector of net emission flows dependent on production and abatement expenditure $\mathbf{E}(F(\bullet), \mathbf{a})$. The marginal cost of abating pollutant *j* is $e^j(t) := -(\partial E^j(\bullet) / \partial a^j(t))^{-1}$. This formulation assumes that the cost of air emissions is accounted for in agents' decisions justifying why they spend resources on abating pollution. This assumption can be justified by the change in consumer habits due to increasing awareness of air emissions damages, or the introduction of stricter laws and policies regulating air emissions. The matter for comprehensive national accounting is that emission costs are not included in any conventional economic aggregate.

In order to maximize welfare subject to (4), (5) and (6), the central planner controls are $C(t)$, $\mathbf{R}^d(t)$, $\mathbf{R}^X(t)$, $\mathbf{R}^M(t)$, $\mathbf{a}(t)$ and $M(t) - X(t)$. Net national product according to national accounts' procedures is interpreted as $NNP := C + \dot{K} + \dot{K}^f$. Note that according to the general model NNP and all other variables in GNNP and GS should be used in constant prices, deflated

[3] Bear in mind that the production function used here allows for endogenous growth since human capital is a form of capital included in the model. So, time as a factor of production represents exogenous technological progress as opposed to the endogenous technological progress associated to human capital growth.

by a comprehensive CPI that includes all things that affect welfare. The best proxy at hand is the usual CPI. According to the results of the previous section,

$$\text{GNNP: } Y = P^C \left\{ NNP + (\mathbf{Q}^R - \mathbf{f_R}) \cdot \dot{\mathbf{S}} - \mathbf{e} \cdot \mathbf{E} + Q^t \right\}, \tag{7}$$

$$\text{GS: } Q\dot{K} + Q^t = P^C \left\{ NNP - C + (\mathbf{Q}^R - \mathbf{f_R}) \cdot \dot{\mathbf{S}} + Q^t \right\}, \tag{8}$$

$$\text{with } Q^t(t) = \int_t^\infty F_s e^{-R(s-t)} ds, \tag{9}$$

where P^C is the price of the consumption good and is set equal to unity when the marginal cost of emissions is constant, according to

$$\frac{\dot{P}^C}{P^C} = \frac{\dot{\mathbf{e}} \cdot \mathbf{E}}{\left(C - \mathbf{e} \cdot \mathbf{E}\right)}. \tag{10}$$

Expression (10) was obtained by applying the Divisia price index condition. It is likely that the estimates of GNNP and GS are altered if the marginal cost of emissions is not taken as constant. The adjustments necessary to reach GNNP from the usual NNP are shown in (7) and (8), i.e., deduct the welfare cost of emission $\mathbf{e} \cdot \mathbf{E}$, deduct (add) the value of rents from resource stock depletion (appreciation) $(\mathbf{Q}^R - \mathbf{f_R}) \cdot \dot{\mathbf{S}}$ and add the value of time. These are the expressions we will estimate for Portugal in 2000 prices.

3. Comprehensive accounting results

3.1 Pollution emissions and valuation

The term to be included in the GNNP is the product of the vector of emission flows by an estimate of the marginal abatement benefit or cost, also termed the marginal damage cost (MDC). On the optimal path both these prices are equal. Assuming the case of overpollution, then MDC is an upper bound on the marginal value of emissions since then the marginal abatement costs are below and emissions are above the optimal (Hamilton and Atkinson, 1996). We used data for MDC rather than for marginal abatement costs, because only the former were available.

We wish to account for the damages due to emissions of the following flow pollutants: sulphur dioxide (SO_2), nitrogen oxides (NO_x), particulate matter (PM2.5), ammonia (NH_3) and volatile organic compounds (VOC). These pollutants and associated impacts are considered to account for a large part of the total damages from air emissions (Holland et al., 2005). These impacts are the health damages of PM2.5 (both acute and chronic effects) and O_3 (only acute). The quantification of health impacts addresses the impacts related to both long-term (chronic) and short-term (acute) exposures. The quantification deals with both mortality (i.e. deaths) and morbidity (i.e. illness). The morbidity effects include major effects – hospital admissions and the development of chronic respiratory disease – and also less serious effects likely to affect a greater number of people, such as changes in the frequency of use of medicine to control asthma, and days of restricted activity. When the impact and the values are combined in the analysis, the most important health related issues relate to mortality, restricted activity days and chronic bronchitis (Holland et al., 2005).

The emission data is available in the National Inventory Report (2007) for the period 1990 - 2005. The marginal benefits/damages of emissions were obtained from the reports of the Clean Air For Europe (CAFE) programme (Holland et al., 2005). A change of 1000t in the emissions of the considered pollutants is modeled (with physical and chemical processes) to provide an estimate of the concentration of PM2.5 and O_3 in 2010 in the form of a matrix for Europe. Using source-receptor functions and contingent valuations to estimate the value of a statistical life or life year, these changes in concentration are monetized. The two methods that can be used – value of statistical life (VSL, applied to the change in number of deaths) and value of life year (VOLY, applied to changes in life expectancy) – have contrasting strengths and weaknesses. Some sensitive analysis is considered by changing the valuation of mortality, by considering two thresholds above which ozone health effects are considered (35 ppb and 0 ppb), and by changing the set of health functions. Given that chronic conditions typically take time to develop and persist for a number of years, as opposed to acute effects, the monetized values were discounted consistently with CAFE that adopts the rates used by DG Environment of 4%, with a sensitivity analysis range of 2% and 6% (Holland et al., 2005). In table 1 we present the prices used to calculate $\mathbf{e} \cdot \mathbf{E}$ (converted to € of 2000).

[Table 1]

The best estimate corresponds to chronic mortality based on mean VOLY estimates of €120,000 with no threshold for ozone. The low estimate uses the median estimate of VOLY of €50,000 for mortality impacts of PM2.5 and ozone with the 35 ppb threshold. The high estimate uses the mean VSL estimate of €2,000,000 for mortality impacts of PM2.5 and mean VOLY for ozone without threshold. Figure 1 shows the costs of emissions as percentage of the total cost for the best estimate. All the prices estimated were assumed constant throughout the accounting period, hence MDC equals average costs.

[Figure 1]

Particulate matter, followed by SO_2, is the biggest contributor to total damages from air emissions accounting on average for more than half of total costs. But whereas, the emissions of SO_2 decrease, the emissions from PM2.5 increase, reaching 60% of total emission costs. As a % of GNI, the relative to national income, the damages from air emissions have been decreasing. From 1990 to 2005 the best estimate is that the cost of air emissions in Portugal averages 8% of GNI decreasing from 9% in 1992 and 6% in 2003, where the high estimate averages 11% and the low 4% of GNI.

These values are higher than the estimates of Hamilton and Atkinson (1996) for the pollutants CO_2, SO_2, NO_x and PM10 for Portugal. They found that total air pollution damage is 1 to 8 % of GNI. In previous studies like Pezzey et al. (2006) and the World Bank's adjusted net savings, the damages from the greenhouse gases (GHG) were included. Accordingly, the latter model treats GHG as stock pollutants, while the former model only allows for flow pollutants, which is not a satisfactory description of GHG. Here, we do not address stock pollutants.

The CAFE project estimates the MDC including the health impacts described above, but also including the yield loss of crop production due to ozone. It is important to note that any yield loss of market goods and services is being measured by the conventional calculations, since GDP measures any change in production irrespective of the cause. This implies that in order to use the CAFE marginal damages estimates in our model we must assure that any effects from pollution emissions that are already reflected in national product are not included in the estimation of marginal damages estimates. It is convenient that the CAFE presents the quantified crop damages separately, because then it suffices to subtract these values from the marginal estimates, avoiding double counting. In any case, the crop damages are negligible compared to the health costs. By the same token, taking into account the acute effect of restricted activity days due to air emissions is a potential source of double counting, since in principle the corresponding loss of production is already being revealed in GDP. We could not, however, distinguish the emissions' effects on restricted activity days for Portugal.

3.2 Depreciation in commercial Portuguese forests

Here we present the data used to estimate $(\mathbf{Q}^{R} - \mathbf{f_R}) \cdot \dot{\mathbf{S}}$ in (7) and (8). We have considered the 3 most important commercial sources of wood in Portugal, that is, cork, conifers and eucalyptus forests. In 1995, the main function of 51.8% (24.4% of conifers, 17.7% of broad-leaves and 11.6% of mixed stands) of forestland was wood supply, and the second function, corresponding to 48.2% of the forestland, was non-wood forest products, mostly cork production in the southern regions (Mendes, 2005). In 1998, the forest sector represented 2.93% of GDP, which places the country in a top position within the EU 15. Most of this value added was due to cork products. Corks exports are the most important part of total Portuguese forest exports. However, since Mendes (2005) argues that 'it is believed that the industrial demand for cork induces harvesting of all sustainable production' but not more, we have considered the net growth of "cork forests", $\dot{\mathbf{S}}$, equals zero when estimating the depreciation of commercial forests, according to (7) and (8).

We estimate $\dot{\mathbf{S}}(t)$ directly with the data obtained from the National Forest Inventory 2005/06 (IFN) of the DGRF (Direcção-Geral dos Recursos Florestais[4]) for the years 1990, 1992, 1995 and 2005 in hectares. The data on volumes of standing stock (m³/ha) was also obtained from the IFN 2005/06. This allowed us to calculate the volume of the stocks of $\mathbf{S}(t)$. Information on prices was obtained through the SICOP system[5], for the period 2000 - 2005, and directly from DGRF for the period 1990 - 1995 based on roadside prices. Our own linear estimations completed the time series for the period 1990 – 2005. An estimate of the marginal cost of harvesting of 7 €/m³ was obtained through inquiries with several providers of forest services. Figure 2 presents the forest depreciation by species in Portugal.

[Figure 2]

The Portuguese commercial forests considered here have been depleting from 1990 to 1993 and from 1996 to 2005, especially pine forests. Between those periods the forest appreciated in net value, mostly due to increases in the area of eucalyptus. Increasing the marginal costs of extraction would lower the value of the depreciation of commercial forests throughout. Compared to GNI, the depletion of forest resources ranges between the maximum depreciation of 0.4% and the highest appreciation of 0.2%, with an average depreciation of 0.1%. This corresponds to an average yearly loss of 120 million €. In Portugal, the value added of the forest sector is around 3 %, which implies that, when at its highest values, the depreciation of commercial forests is of the order of 10 % of the value added of the forest sector. This has the interpretation that the forest value added should have been 10 % less, to account for (the loss of welfare due to) the loss of future timber due to harvest in the current period.

As described above, for the change in stock we used $A_t V_t - A_{t-1} V_{t-1}$, where A_t represents area in hectares and V_t is the volume in cubic meters per hectare in year *t*. Since the data available is not

[4] www.dgrf.min-agricultura.pt/

[5] Sistema de Informação de Cotações de Produto Florestais na Produção - http://cryptomeria.dgrf.min-agricultura.pt/

on an annual basis, we have approximated a linear trend, both for area and for volume, for the years in between. The consequence of this is that the changes in stock have jumps whenever new (and different) data arrives. From figure 3, in the case of eucalyptus, the jumps in 1993, 1996 and 1999 are due to new information on hectares and the mild changes are due to price changes. Regarding conifers, an increase in pine area in 1993 is responsible for the estimated decrease of depreciation. The spikes in 1995, 1999 and 2005 are due to data on volume of standing timber that is only available for 1994, 1998 and 2004. These changes reflect a artificial effect implied by the use of data for longer periods than on a yearly basis and calculating differences on a yearly basis. These effects are analyzed in sub-section 3.5.

In the introduction we mentioned that the World Bank estimates the depletion of forest resources for all countries in the world. In their estimates, net natural growth is not added to savings when it is positive, therefore this will bias the estimates against sustainability. This is the case for their estimates of Portuguese's forests but contradicts our findings that the commercial stock of forest timber has declined for most of the accounting period.

3.3 The value of technological progress

Including the value of technological progress requires estimation of (9). Data on total factor productivity (TFP) annual growth rates for Portugal was obtained from the AMECO database.[6] We consider this to be our estimate of F_t/F. Regarding the data, TFP growth roughly accompanies GDP growth and both rates are close, especially near and after recessions. Particularly, both TFP and GDP roughly depict a ten year business cycle with decreases in 1975, 1984/85, 1993 and 2003. As expected, when growth is low, for instance due to weak internal demand as was the Portuguese case in the beginning of the 90's, TFP growth decreases, for instance when firms seek increases in productivity using strategies that do not involve more use of the traditional factors of production. When GDP growth is high, the shares of GDP growth

[6] This is the annual macro-economic database of the European Commission. http://ec.europa.eu/economy_finance/indicators/annual_macro_economic_database/ameco_en.htm

attributed to labor and capital increase, implying a deceleration and sometimes a decrease in TFP. Since the value of technological progress is forward-looking we need projections of TFP growth and GDP growth. This was estimated by extending a long term average growth of GDP (1974-2007) of 2.5% and TFP growth of 1% until 2020 and using (9) truncated to 17 years. We performed sensitivity analysis for various truncations of (9). After 2020, a rate of 1% was used for the yearly growth of GDP and TFP in order to calculate the integral truncated for T=20, 40, 60, 80 and 100 years. The results are depicted in figure 3.

[Figure 3]

Note that the integral is converging to a value more than double of the initial estimate. The tradeoff is between uncertainty of the scenarios of future growth and the accuracy of the value of the integral. For T=17, the value of technological progress in (9) amounts to 6 to 13 % of GNI, averaging 9%. For the truncation of T=100, the value of time averages 30% of GNI, a considerable change in value showing that, with a 4% discount rate, a truncation of (9) for 17 years leaves out important contributions to GNNP and GS. Moreover, the TFP growth during the accounting period was responsible on average for 38% of GDP growth. In spite of the short run fluctuations, during the accounting period, both the value of technological progress and the TFP growth are decreasing shares of GDP and GDP growth, respectively. After 2001, the value of technological progress as a share of real GDP depicts an inversion of this tendency, as figure 3 hints to. The increase from 2001 on is mostly explained by the projections for TFP growth of 1% and GDP of 2.5% until 2020 (always positive).

The real interest rate used in (9) is 4% in accordance to the assumptions for the estimates of marginal damages from air emissions in section 3.1. It is important to maintain consistent assumptions of all the terms in GNNP and GS because frequently the data gathered was constructed for a different purpose with its own set of assumptions. The TFP growth accounts for any GDP growth that is not attributable to changes in physical capital and labor. So, it accounts for both exogenous and endogenous technological progress. As discussed in sub-section 2.2 the model requires exogenous progress only, which implies that TFP data from usual growth accounting provides an overestimate of exogenous technological progress required by the model. Moreover, the estimate of TFP assumes a particular production function, and it is known that using different specifications can drastically alter the estimate of TFP (see for instance Ayres and Warr, 2005). Tzouvelekas et al., (2007), performing growth accounting with CO_2 emissions as a factor of production, find that TFP could be under or over estimated. The comprehensive accounting model should use the same production function as the one used to estimate TFP. However, green accounting models usually include production factors uncommon to growth accounting, like natural resources or environmental quality. This is a possible source of inconsistency of the estimates of GNNP and GS that could not be dealt with here. The above results seem at first sight to reinforce the idea from Weitzman (1997) that the evaluation of sustainability appears to depend more critically on future projections of TFP than on the typical corrections now being undertaken in environmental accounting. However, we know that TFP is overestimated, and there is no indication that the value of exogenous TFP is not close to zero.

3.4 Green net national product and genuine saving

To estimate GNNP and GS using (7) and (8), data on GNI, consumption of fixed capital (CFC), CPI and gross saving was obtained from the AMECO database. The GNI, CFC and gross saving were originally in current prices and then deflated to constant € of 2000 by using the CPI according to the theory of section 2. Figure 4 presents the estimated terms in (7) and (8), including the estimate of GNNP with (9) truncated to T=100. If not stated otherwise, the value of time used is truncated for 17 years.

[Figure 4]

The CFC is subtracted from GNP to obtain NNP. During the accounting period, depreciation of physical capital ranges from 14% to 17% of GNP with an increasing trend, contributing negatively to welfare and hence, sustainable development. A greater share of total production of the economy is being used to offset the out-of-date capital, in part due to the increasing use of computers and other new technologies' capital with high depreciation rates. So, there is an increase in depreciation related to technical innovation, suggesting that using a constant depreciation rate in section 2 is incorrect. However, here we do not address this issue further.

To correct for the loss of welfare due to air pollution the total cost of emissions of air pollutants of section 3.1 should be subtracted from NNP. The value of the depletion of commercial forests and the value of technological progress was then added to obtain the GNNP for Portugal. Although a mild trend towards the appreciation of commercial forests is noticed, the depreciation term contributes negatively to welfare. Moreover, despite being a relatively small impact on welfare, it has an impact on the sustainability message as should become clear below. Overall, GNNP is always positive with an increasing trend, suggesting that welfare increased during the accounting period. Using the value of time for T=100 increases the GNNP by 25% becoming higher than GNP. Regarding GS, figure 5 depicts three estimates of (8).

[Figure 5]

The GS was obtained by adding the value of time and depreciation of commercial forests to net saving ($NS = NNP - C$) following (10). When the value of technological progress is included, GS is always positive and if estimated with T=100, GS is three times higher than with T=17. It is, however, noticeable that all estimates show a decreasing trend and that without including Q^t , GS is negative after 2002, indicating unsustainability. Table 2 presents the relative values of net saving, and four estimates of GS.

[Table 2]

We now analyze the sustainability message of the various estimates of GNNP and GS, and its relation to more common aggregates like GNP, NNP and NS. Looking at real GNP, Portugal had two recessions during the accounting period, in 1993 and in 2003. More relevant for sustainability, the NNP also decreased in those years, but GNNP decreased in 1993 and 1996.

Looking in more detail to 1993, we see that the SO_2 costs of emissions, which represent around 30% of total emission costs, decreased substantially. During the accounting period, the GNP and the (cost of air) emissions more or less moved in the same direction, e.g., decreases in emissions occur when GNP decreases or decelerates. This contributes to an increase in welfare. Regarding forest depletion in 1993, the data shows an appreciation of the commercial forests, mostly due to an increase in eucalyptus area accompanied by an increase in the price of commercial wood. Moreover, the value of time also increased in 1993, but overall this is not sufficient to offset the decrease in welfare due to emissions and decrease in production.

In 1996, GNP growth slows down and with it costs of emissions decreases 5%, the commercial forest stock depreciates due to a decrease in coniferous area and TFP growth decreases by 2 p.p. (implying a decrease of 23% in the value of technological progress). In fact, after 1995, the TFP growth decreased until it reached negative values in 2003, after which it started to increase until 2007. This downward trend reflects sectoral shifts – the weight of the services sector (lower productivity) has increased at the expense of manufacturing sector – and increasing investment in housing sector that has a low productivity, lead to a decline in investment efficiency. All in all, in 1996 the movement of GNNP indicates unsustainability mostly due to the drop in TFP growth.

In 2003, a recession in real GDP was not sufficient to provoke a decrease in GNNP although it decelerated significantly. Excluding the value of time, which after 2001 is strongly influenced by the projections of TFP and GDP growth (section 3.3), the decrease in the cost of disutiliy from emissions offsets the decrease in NNP. In particular, figure 1 shows a considerable decline in SO_2 emissions. Since energy is the major responsible sector for SO_2 emissions, these tendencies reflect the economic slowdown through less energy use, and the introduction of new stricter laws regulating residual fuel oil according to the Portuguese report on the state of the environment.

After 2001, the change in GNNP depicts an increasing trend due to the projections for TFP growth, whereas the change in NNP and GNNP without the value of time presents a decreasing trend, with NNP actually decreasing in 2003.

3.5 Excluding business cycles

Although the analysis of the interactions between terms provides insights into the indication of welfare changes and sustainability, the theory presented in section 2 assumes a competitive economy on its optimal path and so full capacity utilization of stocks at all times. This is approximated by filtering out the short-run fluctuations or business cycles of the variables. These cycles are also not desirable when measuring the long-run sustainability of the economy since, as perceived from the previous section, they impact the sustainability message of the indicators although they may have little to do with long-run economic growth and sustainability.

As stated in sub-section 3.3, the Portuguese economy presents business cycles of roughly 10 years, which are also present in economic data other than GDP. Using a Hodrick-Prescott filter we obtained the trend of the initial time series, approximating the value of the variable in full utilization of resources. This method is based on the assumption that a time series can be decomposed linearly in a trend and a cyclic component. Another way to obtain potential GDP is to follow a production function approach but the difference in the results is small. Following Ravn and Uhlig (2002) a smoothing parameter of 6.25 is adequate for filtering the components with cycles between 9 and 16 years. All the economic terms in (7) and (8) – GNI, CFC, the value of time and NS – roughly present 10 year cycles in phase with GNI cycles. For the environmental corrections, the damages from pollution emissions depict more frequent cycles, whereas the depreciation of forests fluctuates countercyclically to GNI.

The resulting potential GNNP and GS are depicted in figures 4, 5 and table 2. The potential value of technological progress appears in figure 3. The results show that the indications of unsustainability from GNNP, discussed in sub-section 3.4, are related to business cycles, i.e., potential GNNP did not decrease in the accounting period. Therefore there is no indication of unsustainability although potential GNNP shows a markedly decelerating trend. Without the technological progress, GNNP growth presents a markedly decreasing tendency without becoming negative. In respect to saving, including technological progress GS is always positive therefore showing no sustainability problem. However, excluding the value of time, there is evidence of unsustainability after 2002, when GS becomes negative. This is in contrast with positive GNNP growth rates for all the accounting period, which do not indicate unsustainability. In conclusion, excluding business cycles from GS did not change the indication of unsustainability, suggesting that a saving measure of sustainability is less affected by business cycles than a production measure. Altering the truncation of (9) does not change the GNNP's sustainability message whereas GS becomes more positive, i.e., away from unsustainability. This result is also suggested by figure 3 – the difference in truncations did not change the evolution of Q^t, but changed it in absolute terms – and (2) – adding a large but roughly constant term to GNNP does not change the sustainability message, whereas adding the same term in GS can have a significant impact. Also important to stress is that, since TFP is overestimated the analysis excluding the value of time gains importance, and reveals a mismatch between the message of sustainability from GNNP and GS, which is a different form of the mismatch reported in Pezzey et al. (2006).

4. Concluding comments

We have estimated two measures of sustainability from 1991 to 2005, to include the value of technological progress and exclude business cycles. Our main contributions to the literature of green accounting were to estimate the value of time pointing out the effect of the truncation of the integral and to eliminate the short-run cycles of the variables to obtain potential GNNP and GS. Moreover, we discussed the assumptions, possible inconsistencies in green accounting exercises, and compared the sustainability message of the two indicators estimated.

Assuming the data is reliable, GS seems to consistently indicate movement towards unsustainable development, whereas GNNP indicates both no sign of unsustainability and that welfare increased. We report a mismatch in the message of sustainability between GNNP and GS without the value of time. Genuine saving indicates unsustainable development of the Portuguese economy after 2002 when the value of technological progress is not accounted for. Overall, the adjustments proposed are around 15% of GNI, being the environmental adjustments – depletion of forest resources and cost of air emissions – of the magnitude of 7% of GNI. The later may seem small; however, we did not include relevant stocks of natural capital as fish, mineral, water, soil; or environmental amenities such as biodiversity, landscape and other types of constraints like the proximity of thresholds in ecosystem dynamics. For instance, based on a willingness-to-pay (WTP) study of visits to the Peneda-Gerês National Park, Mendes (2005) estimates the value of forest landscape and biodiversity conservation to be 36.3 € ha^{-1} yr^{-1}, or 19.55 million € yr^{-1} for the total Natura 2000 sites in 1996. Regarding the agricultural sector, Marta-Pedroso et al. (2007) estimated a value WTP of 446 € ha^{-1} $year^{-1}$ to preserve the cereal steppe for scenic value and birds' habitats. However, due to the uncertainty related to the aggregation of the above values for Portugal we decided not to include them here. This, however, exemplifies that considerable contributions are left out of the GNNP and GS expressions. We believe a substantial change in the results should be evident when including these effects which might influence the sustainability message of GNNP, as is the example of the depletion of commercial forests discussed in section 3.4.

This could be the case of air emissions as Holland et al. (2005) state that to estimate the MDC, the values included health effects in full, leaving out of the assessment the degree to which they are already internalised. In particular, future work should be done to avoid double counting regarding the chronic effects. Also, including the value of technological progress may be problematic since it has an important role in indicating sustainability, but using overestimated TFP data is not adequate for green accounting. Thus, there is a need for green growth accounting estimates. Another source of error is the forward looking integral in the value of time. It seems that the discount term is not high enough to allow a safe truncation of the integral to just 20 or so years (most of the scenarios encountered) without excluding significant contributions to welfare from the future.

Regarding savings, the conventional NS have the drawback of considering wrongly as consumption some types flows that should be investments. Hamilton and Clemens (1999) refer that education expenditures should be considered a proxy for investments in human capital. We did not use this approach here since, at least for Portugal, the education expenditures (very high) are believed not to reflect satisfactorily the yield in human capital. This contributes positively to GS. We should stress that the indicators used here were derived for instantaneous changes in the variables, and in fact it is true that decreasing GNNP or negative GS indicate welfare losses, but only locally, i.e., negative GS now indicates that welfare is decreasing it does not indicate that it will continue to decrease or when will utility decrease in the future, according to (3). In any case we believe a sound relationship between theory and data is essential to develop measures of welfare and sustainability. For that matter, we have to guarantee that the various assumptions associated with the data and the comprehensive accounting growth model, do not conflict.

Acknowledgments

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Tables and Figures

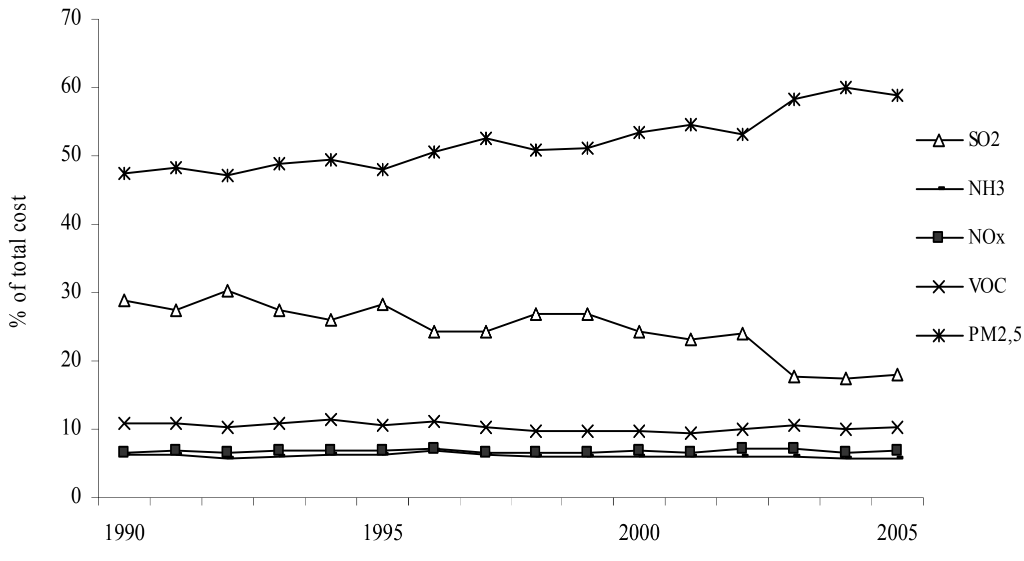

Figure 1 – Cost of air emissions per pollutant as percent of total costs. Best estimate.

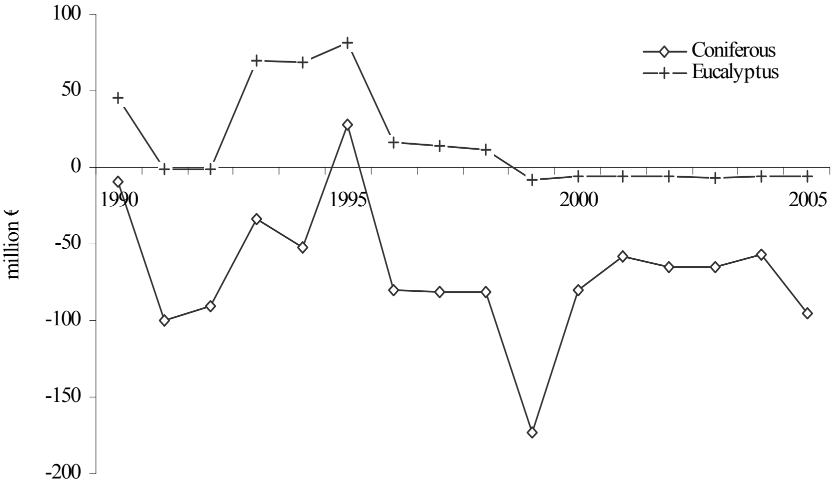

Figure 2 – Forest depreciation by species in Portugal.

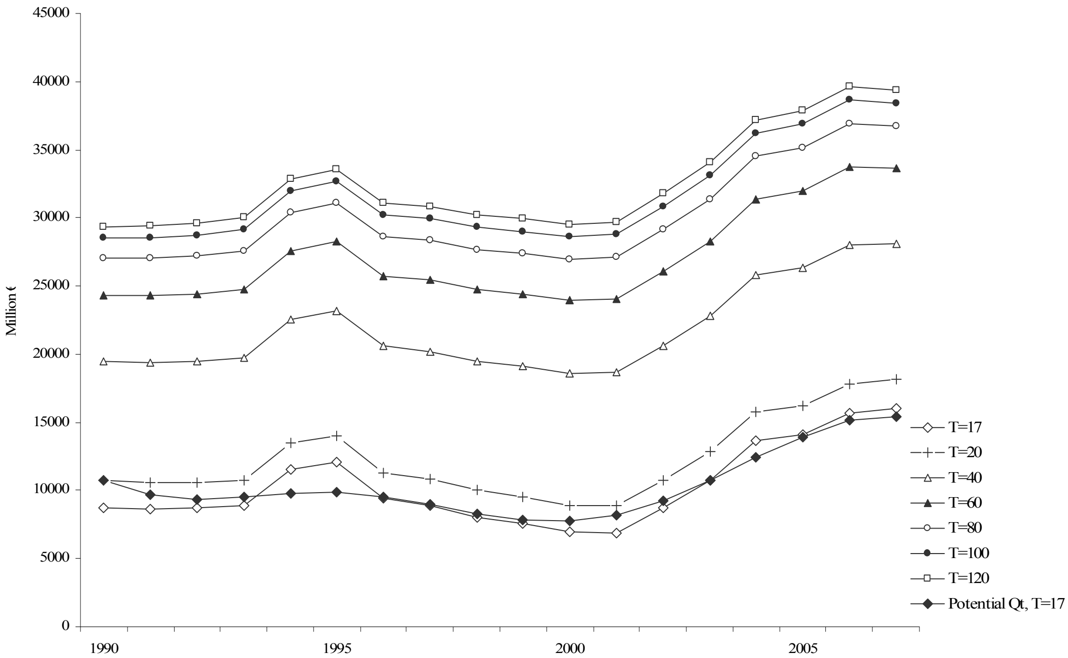

Figure 3 – The welfare value of technological progress in Portugal for several truncations of (9), including the potential value of time for T=17 years.

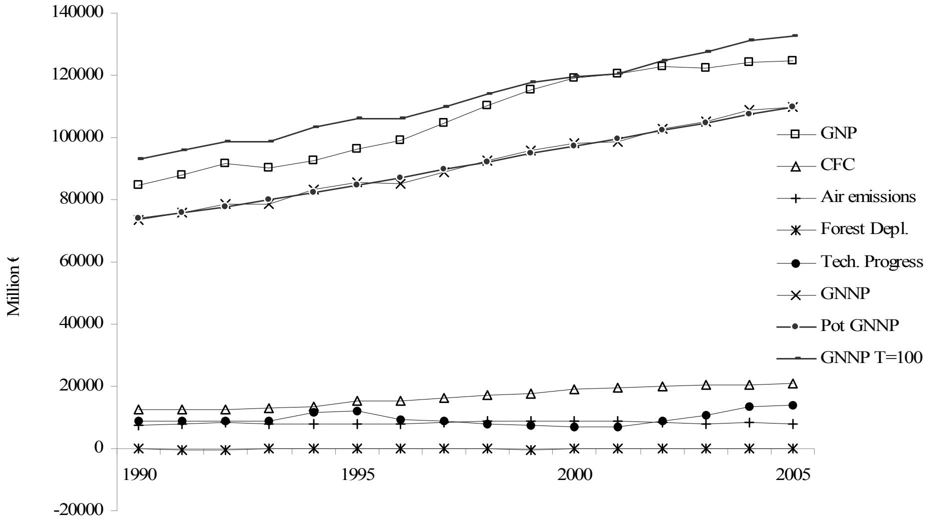

Figure 4 – Green net national product and its components. As a sensitivity analysis, the estimate of GNNP when the value of time is calculated with T=100 is also depicted. The cost of air emissions is positive here although it is subtracted in the calculation of GNNP.

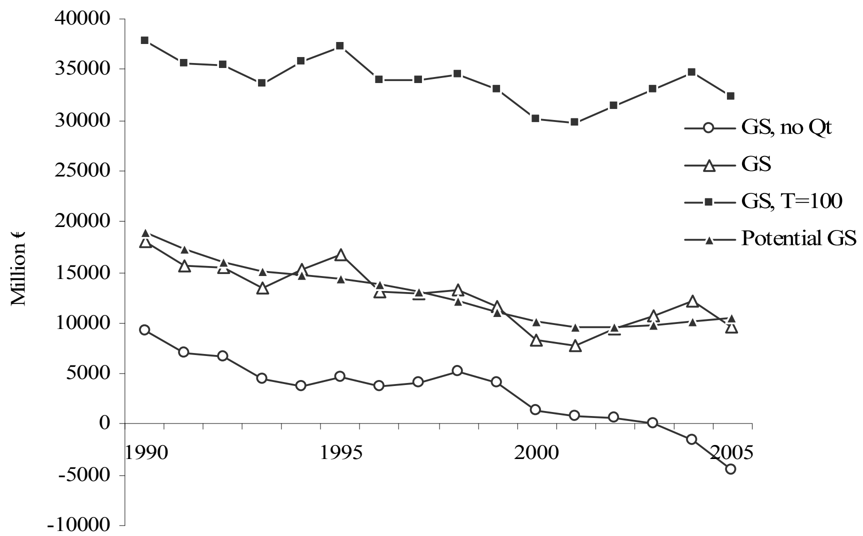

Figure 5 – Genuine saving estimates for two truncations of the value of technological progress (T=17 and T=100), excluding the value of technological progress and potential GS.

Table 1 – Estimates of marginal damage costs by air pollutant in Portugal [€2000/ton].

[€2000/t]	Best	Low	High
SO_2	6872	3472	9972
NH_3	7399	3699	10999
NO_x	2040	1140	3040
VOC	1150	450	1550
PM2,5	44000	22000	64000

Table 2 – The sustainability message. Negative values, suggesting unsustainable development, are inside boxes.

Growth rates [%]	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
GNP	3,8	3,8	-1,1	2,5	4,1	2,7	5,6	5,5	4,6	3,3	0,9	2,0	-0,2	1,4	0,5
NNP	4,4	4,5	-1,4	2,3	2,4	2,7	5,7	5,8	4,5	2,5	0,6	1,9	-0,3	1,2	0,5
GNNP	3,5	3,6	-0,1	5,7	2,9	-0,4	4,3	4,3	3,7	2,2	0,6	4,0	2,3	3,5	1,0
GNNP, T=100	2,9	3,0	0,1	4,7	2,5	-0,1	3,6	3,6	3,2	2,0	0,6	3,5	2,1	3,0	1,0
GNNP, no Qt	4,2	3,9	-0,4	2,6	2,6	3,2	5,5	5,8	4,7	3,0	0,6	2,4	0,3	0,8	0,7
Potential GNNP	2,5	2,7	2,9	3,1	3,0	2,8	2,8	2,8	2,7	2,6	2,6	2,6	2,6	2,4	2,1
Potential GNNP, T=100	2,4	2,4	2,5	2,6	2,5	2,4	2,5	2,5	2,4	2,3	2,3	2,3	2,3	2,1	1,9
Potential GNNP, no Qt	4,6	3,7	3,1	3,0	3,2	3,6	3,9	3,9	3,6	3,0	2,3	1,7	1,2	0,9	0,7
(1991=100)															
Net Saving	100	96	61	51	60	53	57	73	60	21	14	11	2	-19	-59
GS	100	99	85	98	106	84	83	85	74	53	50	60	69	77	61
GS, no Qt	100	96	64	53	66	53	58	75	58	20	13	9	0	-22	-64
GS, T=100	100	100	94	101	105	96	96	97	93	84	83	89	93	98	91
Potential GS	100	93	88	85	84	80	76	70	64	58	55	55	57	59	61
Potential GS, T=100	100	97	96	95	95	94	92	90	88	86	85	85	87	88	90
Potential GS, no Qt	100	88	75	65	60	57	54	51	43	31	18	4	-12	-29	-46